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Short communication

Allometries of *Acer negundo* for a better space management in two cities of northeastern Greece

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Abstract

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The ability to estimate the space volume that a tree occupies, in various heights, is a crucial factor in designing the street trees schedule in pavements of new urban infrastructures. The dimensions of *Acer negundo* tree crown in various heights can be the basis for a better space management in the pavements of cities. In this study, the height and the crown width of the *A. negundo* street trees in the Greek cities of Orestiada and Alexandroupoli and the allometric relations that can be found between them, were investigated. Data from 117 street trees growing in semi-permeable pavements of the two cities were used. In each selected tree, the total height (H), and the maximum and minimum crown diameter (CW) were measured. The selected model (CW-H) for Alexandroupoli exhibits a coefficient of determination (R^2) of 0.81. The R^2 of the model selected for Orestiada is lower ($R^2 = 0.66$). The R^2 of the model selected using the complete dataset is 0.77. *A. negundo* appears to have greater crown width in Alexandroupoli compared to that of Orestiada. In Orestiada the conditions of growth were variable since in many cases the measured trees were under side shade, while this not the case in the corresponding trees in Alexandroupoli. The better fit of the selected model in Alexandroupoli compared to that of Orestiada is probably due to the more variable growth conditions of Orestiada.

Keywords

Acer negundo, allometric relationships, crown width, height, urban trees

Introduction

Street trees improve quality of air and livability of urban areas (Mullaney et al., 2015). Trees in urban areas affect the bioclimatic conditions and can mitigate high levels of heat in buildings and cities, depending on their spatial distribution (Donovan et al., 2009; Mazhar et al., 2015). Moreover, street trees can be used for the cooling of the microclimate and the reduction of thermal loads during summer days (Gillner et al., 2015).

Allometric relationships between tree characteristics can help urban green managers, among others, to estimate the growth of trees in urban landscapes, to plan plantings and generally to achieve their goals (Troxel et al., 2013; Hui et al., 2020).

The tree diameter is commonly used in allometries of trees (Dais et al., 2022). In studies conducted in urban areas, a strong relationship between the crown width and breast height diameter has been found (Semenzato, 2011; Troxel et al., 2013; Coombes et al., 2019). Vaz Monteiro et al. (2016) referred that a correct estimation of crown width from breast height diameter can be achieved.

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However, the relationship between tree diameter and crown width (or another tree characteristic) does not provide adequate information regarding the volume of space occupation (and requirements) of a tree.

The space requirements and occupation of a street tree in pavements are mostly determined by the height of the tree and its crown dimensions. One of the most easily measured crown characteristics that influence the space requirement of a tree is crown width.

The ability to estimate the space volume that a tree occupies, in various heights, is a crucial factor in designing the street trees schedule in pavements of new urban infrastructures, since the use of trees of large dimension in pavements not having the analogues dimensions can create large problems in city infrastructures, residents and in trees themselves (Dafis, 2001; Milios et al., 2005). Moreover, in already existing pavements, the knowledge of the dynamic of tree space requirements as the tree grows taller will help in the selection of the most suitable species for the establishment of street trees lines. In Greece urban environments, in many cases, the street trees having large dimensions grow in small pavements as a result of improper tree species selection.

For the achievement of the best possible result in urban greening, the species selected for street trees have to exhibit wide ecological tolerances in order with stand adverse conditions (Dafis, 2001). One such species is *Acer negundo* L. It exhibits durability in extreme conditions such as drought and flood and adapts in all types of soils from heavy clay to sandy (Burns and Honkala, 1965). It is a small to medium tree size with 15–23 meters height (Burns and Honkala, 1965) that under non-limiting resources (such as light and nutrient conditions) presents high growth rate (Porté et al., 2011). The geographical distribution of *A. negundo* is in America, and it extends from Canada to Guatemala (Burns and Honkala, 1965). It is an invasive, species found in industrial and ruderal areas (Erfmeier et al., 2011) forests (Porté et al., 2011; Terekhina et al., 2020) and urban areas (Straigytė et al., 2015; Sikorska et al., 2019). *Acer negundo* can negatively affect biodiversity (Sikorska et al., 2019; Nikolaeva et al., 2020); however, it has some advantages in urban environments, since it is relatively tolerant in polluted environment (Dineva, 2005) and ex-

Fig. 1. Location of the studied cities (Alexandroupoli, Orestiada).

hibits minimum photo-permeability (Dafis, 2001).

In Greece, *A. negundo* is found in parks and as street trees along the roads (Athanasiadis, 1986).

There is no detailed knowledge of the dendrometric characteristics of the individuals of the species that grow in the urban green in various cities of Greece and the world, nor of the relationships that are developed between them. The dimensions of *A. negundo* tree crown in various heights can be the basis for a better space management in the pavements of cities.

The aim of this research is to study *A. negundo* in urban environments of Evros region in north-eastern Greece. The height and the crown width of the *A. negundo* street trees in the cities of Orestiada and Alexandroupoli and the allometric relations that can be found between them were investigated.

Materials and methods

Site description

The study was conducted in Alexandroupoli and Orestiada, the biggest cities in the Regional Unit of Evros, which is in the northeastern part of Greece (Figure 1). The climate of Evros is a combination of Central Europe and Mediterranean climate (Matzarakis, 2006). Alexandroupoli, the capital of Regional Unit of Evros has 61,702 residents (Municipality of Alexandroupoli) (https://www.alexpolis.gr/). The mean annual temperature is 15.4 °C and the average annual precipitation is 575.6 mm (Matzarakis, 2006). Population in Orestiada is 18,426 residents (Municipality of Orestiada) (https://www.orestiada.gr/). The average temperature is 14.6 °C and the average annual precipitation is 579.8 mm (Matzarakis, 2006).

Methods of investigation

Random sampling was applied to locate trees in Orestiada and Alexandroupoli. In order for a randomly sampled tree to be included in the dataset, certain conditions had to be fulfilled. The tree crown had to grow without obstacles such as the crown of another tree or buildings. In case it was in a proximity to the crown of another tree (or building – infrastructure) the crown of the selected tree had not to be deformed, and its branches had not to change growth direction as a result of the existence of other tree branches or of an obstacle. The trees had to be robust and healthy, without signs of recent pruning, or infection by insects, or injuries from human activities. The final dataset included 117 street trees growing in pavements; 60 from Orestiada and 57 from Alexandroupoli. In each selected tree, the total height (H) (with a Blume-Leiss instrument), maximum and minimum crown diameter (CW) were measured. Then the tree crown diameter was calculated as the average of the maximum and minimum crown diameter (Gülçin and Bosch, 2021). As for the type of pavement, the usual pavements, which are covered with semi-permeable (at the joints) slabs, were found in both cities.

Statistical assessment

Data (CW-H scatterplots) suggest that crown width increases as height increases, following a trend that could be either linear or curve, with a constant term, as shown in Figure 2. This lead to test the following eleven regression models for fitting (Arlinghaus, 1994, Table 1). Firstly, we checked the significance of regression coefficients; then we calculated three comparison criteria (Kitikidou, 2005) and selected the best regression model for Crown Width estimation. Residuals' autocorrelation was checked via the Durbin-Watson statistic (Durbin and Watson, 1950, 1951). Field (2009) suggests that values under 1 or more than 3 are a definite cause for concern regarding residuals' autocorrelation. All four statistics are shown in Table 2.

Results and discussion

Summary statistics are given in Table 3.

Regarding regression coefficients' significance, the 95% confidence intervals for all coefficients did not include zero; therefore, they were statistically significant. Statistical comparison criteria with optimum value, for each dataset, are highlighted in Table 4. Based on these results, the cubic model seems to be suitable, for all three datasets. The DW statistic of the cubic model, for each dataset, is within the range [1,3], indicating that residuals' autocorrelation is not present for the suggested models. The selected models, for each dataset, are:

$CW = -0.499 + 1.046H - 0.013H^2 + 0.001H^3$

for Alexandroupoli,

$CW = 15.187 - 4.878H + 0.702H^2 - 0.028H^3$

for Orestiada,

$CW = -1.017 + 1.409H - 0.079H^2 + 0.004H^3$

for the complete dataset.

Homogeneity (Levene, 1990) and normality (Jarque, 2011) tests are applied to the residuals of the selected models (Table 5). Each curve is illustrated in Figure 3.

The use of trees in the urban environments and the benefits they offer has long been recognized (Dafis, 2001). The canopy coverage from surrounding trees and the canopy height have positive correlation in shade provision. Large trees or street trees with the expansive canopy are more effective to increase shade coverage (Li et al., 2018).

However, the accurate evaluation of the required space for the urban trees, the services they provide and their size – depended functions are complicated because crown size is depended on species, tree age and resource (Pretzsch et al., 2015; McPherson et al., 2016). Pretzsch et al. (2015) developed mean allometric relationships between diameter and various tree dimensions (mainly crown dimensions) using a data set of measurements of tree crown that came off around the world and originated by 22 tree species that are used in urban areas. Their study, among others, supports the selection of species and the estimation of their requirements of space.

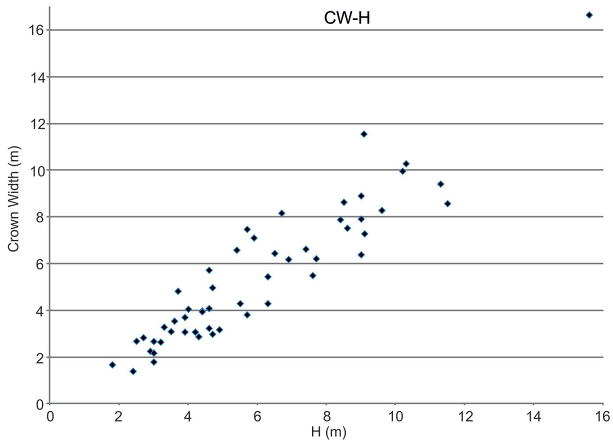

Fig. 2a. CW-H scatterplot for the dataset of Alexandroupoli.

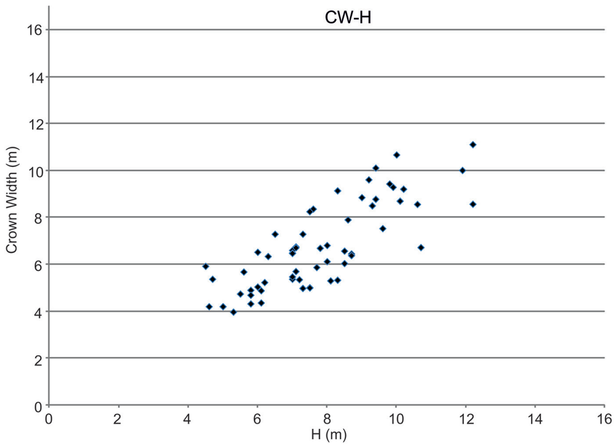

Fig. 2b. CW-H scatterplot for the dataset of Orestiada.

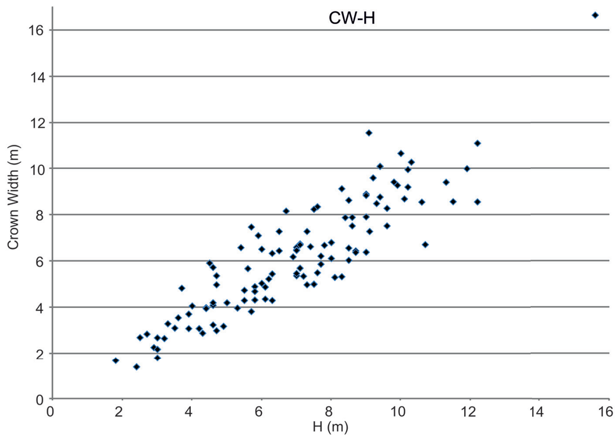

Fig. 2c. CW-H scatterplot for the complete dataset.

McPherson et al. (2016) published tree growth equations (i.e., with age as predictor variable) for 171 tree species planted in urban areas, supporting the estimates made by several computer models used in urban forestry, such as i-Tree.

In the present study, the selected model (CW-H) for Alexandroupoli exhibits a high coefficient of determination ($R^2 = 0.81$). The R^2 of the model selected for Orestiada is lower ($R^2 = 0.66$) but still, it is high enough to use the model for the estimation of crown width from tree height. The R^2 of the model selected using the complete dataset has a value ($R^2 = 0.77$) between the aforementioned coefficients of determination. Vaz Monteiro et al. (2016) studied allometries in seven tree species growing in eight urban areas of Great Britain. In the crown width – tree height allometries, developed for those species, the R^2 values of the developed models were lower than

Table 1. Regression models tested for CW-H fitting

No	Model name	Model
1	Linear	$CW = b_0 + b_1H$
2	Logarithmic	$CW = b_0 + b_1 \ln H$
3	Inverse	$CW = b_0 + \frac{b_1}{H}$
4	Quadratic	$CW = b_0 + b_1H + b_2H^2$
5	Cubic	$CW = b_0 + b_1H + b_2H^2 + b_3H^3$
6	Power	$CW = b_0H^{b_1}$
7	Compound	$CW = b_0{b_1}^H$
8	S-curve	$CW = e^{b_0+\frac{b_1}{H}}$
9	Logistic	$CW = \frac{1}{\frac{1}{u} + b_0{b_1}^H}$
10	Growth	$CW = e^{b_0+b_1H}$
11	Exponential	$CW = b_0e^{b_1H}$

$\widehat{CW}$ estimated crown width (m); H, observed total height (m); b_i, regression coefficients; *u*, upper boundary value = max observed *CW* rounded up.

Table 2. Statistics for selecting the best fitted regression

Criterion	Formula	Optimum value
Coefficient of determination	$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(CW_i - \overline{CW}\right)^2}{\sum_{i=1}^{n}\left(CW_i - \overline{CW}\right)^2}$	1
Standard error of the estimate	$SEE = \sqrt{\frac{\sum_{i=1}^{n}\left(CW_i - CW_i\right)^2}{n-p}}$	min
Root of the mean squared error	$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(CW_i - CW_i\right)^2}{n}}$	min
Durbin–Watson statistic	$DW = \frac{\sum_{i=2}^{n}\left[\left(CW_i - H_i\right) - \left(CW_{i-1} - CW_{i-1}\right)\right]^2}{\sum_{i=1}^{n}\left(CW_i - CW_i\right)^2}$	[1,3]

p, number of regression coefficients, *n*, number of sampled trees; *CW*, observed crown width (m); *CW*, estimated crown width (m); $\overline{CW}$, mean observed crown width (m); H, observed total height (m).

Table 3. Summary statistics for the sampled trees (SD, Standard Deviation)

City	Variable	N	Mean	SD	Min	Max
Alexandroupoli	Total height, *H* (m)	57	5.94	2.92	1.80	15.60
	Crown width, *CW* (m)	57	5.53	3.37	1.40	17.30
Orestiada	Total height, *H* (m)	60	7.78	1.87	4.50	12.20
	Crown width, *CW (m)*	60	6.76	1.83	3.97	11.11
Total	Total height, *H* (m)	117	6.88	2.59	1.80	15.60
	Crown width, *CW* (m)	117	6.16	2.75	1.40	17.30

Table 4. Selection criteria for the eleven tested regression models

No	Alexandroupoli				Orestiada				Total			
	R^2	*SEE*	*RMSE*	*DW*	R^2	*SEE*	*RMSE*	*DW*	R^2	*SEE*	*RMSE*	*DW*
1	0.8127	1.4701	1.4315	1.5099	0.6359	1.1358	1.0786	1.8942	0.7637	1.3423	1.325	1.9036
2	0.7457	1.7132	1.6683	1.6653	0.6159	1.1451	1.1165	2.0545	0.7073	1.4940	1.4748	2.0098
3	0.5981	2.1536	2.0972	1.8099	0.5629	1.2216	1.1912	2.1553	0.5763	1.7973	1.7743	2.0919
4	0.8143	1.4639	1.4256	1.5331	0.6399	1.1088	1.0813	1.9093	0.7655	1.3371	1.3200	1.8975
5	0.8145	1.4632	1.4249	1.5405	0.6598	1.0778	1.0620	1.7722	0.7680	1.3301	1.3243	1.8979
6	0.8141	1.4648	9.8244	0.2309	0.6402	1.1084	>10	0.0868	0.7649	1.3388	>10	0.1461
7	0.7875	1.5661	4.9252	0.3567	0.6172	1.1431	6.5827	0.1317	0.7655	1.3373	5.7087	0.2848
8	0.7414	1.7278	1.8104	1.5699	0.6110	1.1523	1.1380	2.0574	0.6981	1.5171	1.5611	2.0048
9	0.1947	3.0486	>10	0.0716	0.0938	1.7589	5.4982	0.1766	0.1693	2.5167	>10	0.0682
10	0.7178	1.8046	>10	0.5914	0.6300	1.1239	>10	0.0527	0.7141	1.4765	>10	0.2651
11	0.2350	2.9714	>>10	1.9821	0.3384	1.5029	>>10	0.9701	0.1764	2.5090	>>10	1.9707

R^2, coefficient of determination; *SEE*, standard error of the estimate; *RMSE*, root of the mean squared error; *DW*, Durbin-Watson statistic.

Table 5. Homogeneity and normality tests for the residuals of the selected models

Dataset	Normality test	p-value	Homogeneity of variance test	p-value
Alexandroupoli	4.1957	0.1227	1.954	0 .17
Orestiada	4.0998	0.1287	0.498	0.48
Total	0.5832	0.7471	0.024	0.88

those found in the present study. This is observed both in models of each species for the separate urban areas and in the models developed when the total number of trees measured (in all urban areas) for each species that was used. In particular, the highest observed R^2 value for an urban area was 0.65 (*Quercus robur* growing in Bridgend), while the corresponding value when the total number of trees measured was used was 0.67 (for *Fagus sylvatica*).

In our study, according to the selected models (see Figure 3), *A. negundo* appears to have greater crown width in Alexandroupoli compared to that of Orestiada, approximately from the height of 6 m and above. In the height of 12 m, the difference is just over 2.5 m. As al-

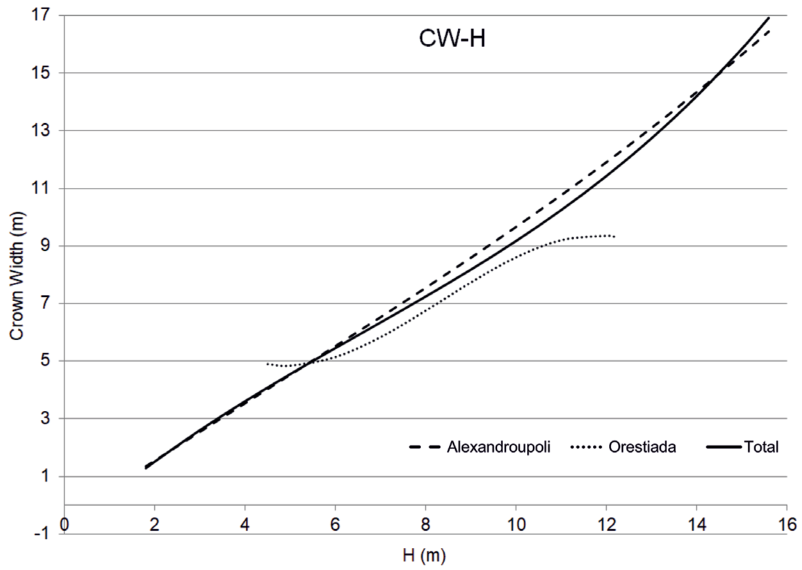

Fig. 3. CW-H regression curves, for each dataset.

ready mentioned, crown size is influenced by resources (Pretzsch et al., 2015).

In Orestiada the conditions of growth were variable since in many cases the measured trees were under side shade, while this not the case in the corresponding trees in Alexandroupoli. This side shade is possible the reason for the lower crown width in Orestiada trees. The crown width difference becomes greater after the height of 10 m, since the negative influence of side shade becomes greater as the age and dimension of trees increase. According to Dafis (1986) the light requirements of a tree are greater as the tree becomes older. Moreover, the better fit of the selected model in Alexandroupoli (R^2 = 0.81) compared to that of Orestiada (R^2 = 0.66) is probably due to the more variable growth conditions of Orestiada. According to Vaz Monteiro et al. (2016) the complex effect of management and environmental factors influence the allometries of trees in urban environments along with the regional climate.

Based on the results of the present study in the designing of establishment of *A. negundo* street trees in Alexandroupoli the model produced by trees measured in that city of Alexandroupoli must be used. On the other hand, in Orestiada in the design of street tree establishment, the model produced by the complete dataset has to be used. However, in order to determine the pavement width for the establishment of trees apart from the height and the crown width of a tree other factors must be considered. Such factors are the road width, the height of tree bole where the crown (branches) appears, the pruning form and intensity, building infrastructure characteristics and others.

More research is needed regarding the space needed for the establishment of tree species used in urban environments and the influence of pruning intensity in allometries of crown characteristics and tree height (or other tree characteristics).

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